Ocean Surface Winds from Space – A Collaborative Education Effort

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***Abstract*- Ocean surface winds play a significant role in the global ocean-atmosphere system. Surface winds drive the worlds ocean currents, transport atmospheric heat and moisture, force nutrient rich upwelling areas, create surface waves and swell, and can reach destructive force in both extratropical and tropical cyclones. Although the oceans cover 70% of the Earth's surface, the network of ocean wind observations obtained from conventional buoys and ships is very sparse. The measurement of ocean surface winds using remote sensing technologies is the only means of obtaining wind information over large portions of the global ocean in a timely manner.**

The Ocean Surface Vector Winds Team (OSVWT) of the Satellite Oceanography and Climatology Division (SOCD) within the NOAA/NESDIS/Center for Satellite Applications and Research (StAR) has been producing satellite-derived ocean surface wind data since the mid 1990s. Wind products from several remotely sensed sources such as QuikSCAT and WindSat are available in near real time (NRT) on the Internet and are also distributed within NOAA. These wind products are used by operational forecasters, scientific researchers and the marine community.

The researchers and forecasters from NOAA Ocean Prediction Center (OPC), the NESDIS StAR Ocean Winds Team and the University Corporation for Atmospheric Research (UCAR) have partnered to increase awareness of the various ocean surface wind vector products available and to develop the educational materials needed to expose these products and to educate teachers at various levels about the latest technology for measuring and interpreting remotely sensed ocean vector winds. To accomplish this it has been proposed to host an educator workshop OPC. This workshop would target educators that train professional and future mariners in meteorology, oceanography and storm avoidance. Teachers from state maritime colleges, federal academies, and professional training institutions would be among those invited to participate. This workshop would be hosted by both researchers and forecasters and held within an operational forecast environment to promote hands-on experience.

This paper will provide background information on current and new ocean surface wind remote sensing technologies, give examples of how products are used within the operational environment, and discuss the development of training material.

I. Introduction

Ocean surface winds play a significant role in the global ocean-atmosphere system. Surface winds drive the worlds ocean currents, transport atmospheric heat and moisture, force nutrient rich upwelling areas, create surface waves and swell, and can reach destructive force in both extratropical and tropical cyclones. Although the oceans cover 70% of the Earth's surface, the network of ocean wind observations obtained from conventional buoys and ships is very sparse. The measurement of ocean surface winds using remote sensing technologies is the only means of obtaining wind information over large portions of the global ocean in a timely manner.

The Ocean Surface Vector Winds Team (OSVWT) of the Satellite Oceanography and Climatology Division (SOCD) within the NOAA/NESDIS/Center for Satellite Applications and Research (StAR) has been producing satellite-derived ocean surface wind data since the mid 1990s. The wind products from several remotely sensed sources (such as QuikSCAT and WindSat) are available in near real time (NRT) on the Internet and within NOAA and are currently being utilized by operational forecasters, scientific researchers and the marine community.

One source of remotely sensed winds available from the NOAA/NESDIS/Center for Satellite Applications and Research (StAR) is the SeaWinds scatterometer onboard the NASA QuikSCAT satellite. The QuikSCAT wind products are fully integrated into the operations at NOAA's Ocean Prediction (OPC) and Tropical Prediction Center (TPC). Both ocean and hurricane forecasters routinely use QuikSCAT winds to define warning areas and improve forecasts. Both the OPC and TPC have been instrumental in assessing the quality of QuikSCAT winds and evaluating their impact on operations. In addition to demonstrating a positive impact, the studies brought to attention the fact that user education and training are essential for the effective utilization of these products within the operational environment.

The researchers and forecasters from NOAA OPC, the NESDIS StAR Ocean Winds Team and the University Corporation for Atmospheric Research (UCAR) have partnered to increase awareness of the various ocean surface wind vector products and to develop the educational materials needed to expose teachers at various levels to the latest technology for measuring and interpreting remotely sensed ocean vector

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winds and to educate them on their use. For example, a gap exists between the knowledge gained by operational forecasters through the daily use of remotely-sensed ocean surface winds and the educational material that is currently used to train mariners on such topics as: extreme ocean storms, storm structure and evolution, the impact of the underlying ocean temperature on near surface atmospheric winds, and forecasting techniques. To help close this gap it has been proposed to host an educator workshop at the OPC. This workshop will target the educators that train professional and future mariners in meteorology, oceanography and storm avoidance. Teachers from state maritime colleges, federal academies, and professional training institutions would be among those invited to participate. This workshop would be hosted by members of the research and forecast community and would be held within an operational forecast environment in order to promote hands-on experience.

Background information on current and new ocean surface wind remote sensing technologies will be given in section II. Section III will discuss the transition of products from research to operations. Section IV contains the evaluation of the use of QuikSCAT data within the operational environment. Data Display capabilities will be illustrated in section V. Section VI will outline the development of training material and the paper will be summarized in section VII.

II. BACKGROUND INFORMATION

Until recently, the primary source of surface wind observations over the oceans has been ship reports through the Volunteer Observing Ship (VOS) program or data buoys. Since ships tend to avoid areas of inclement weather and the current network of data buoys is nowhere near optimal density a substantial data void exists over the open oceans. Many attempts have been made to fill this void using remote sensing instruments flown onboard satellites to measure surface wind speed and direction. Over the past twelve years, OPC forecasters have used the winds derived using space-borne active and passive microwave radar sensors. Scatterometers are active microwave instruments that were specifically designed to measure near surface ocean wind speed and direction. The first scatterometer was flown in space as part of the Skylab missions in 1973 and 1974. In 1978, the Seasat-A Satellite Scatterometer (SASS) was flown on the Seasat-A satellite. However, due to a malfunction the mission only lasted four months. The European Space Agency flew a Scatterometer (SCAT) onboard its European Remote Sensing Satellite-1 (ERS-1) in 1991. Data was gathered for an 8-year period but coverage was limited due to the design of the scatterometer. In 1996, The NASA Scatterometer (NSCAT) was launched onboard the Advanced Earth Observing Satellite (ADEOS-I) and provided 90% coverage of the ocean areas within a 2-day period until the satellite lost power in 1997. The Quick Scatterometer Satellite (QuikSCAT) carrying the SeaWinds Scatterometer was launched in June 1999 to fill the gap created when NSCAT data was no longer available. The SeaWinds Scatterometer on QuikSCAT acquires hundreds of times more observations of surface wind speed and direction each day than can ships and buoys combined. By providing continuous, high-resolution measurements of both wind speed and direction in all weather conditions QuikSCAT has been able to eliminate much of the data void over the oceans. Due to the success QuikSCAT another SeaWinds Scatterometer was launched on the ADEOS-II Satellite in December 2002. However, the mission ended when the satellite suffered a catastrophic power loss.

OPC forecasters have also had access to wind data derived from passive microwave radar sensors such as the Special Sensor Microwave/Imager (SSM/I) available from the Defense Meteorological Satellite Program (DMSP) series of satellites. However, these data were of limited value as SSM/I retrievals consist of wind speed only and not the full wind vector [1.] More importantly, SSM/I is not able to retrieve wind speeds in areas of liquid cloud and precipitation. This is a significant problem since these areas are of very high interest to marine forecasters as they often contain high winds [2]. In January 2004, WindSat (a satellite-based multi-frequency polarimetric microwave radiometer developed by the Naval Research Laboratory Remote Sensing Division) was launched. WindSat is the first polarimetric microwave radiometer designed to measure ocean surface wind speed and direction (the complete wind vector) from space [3.] In addition to the complete wind vector WindSat also provides concurrent measurements of Sea Surface Temperature (SST), Cloud Liquid Water Content (CLW), rain rate and water vapor. WindSat products have been made available to the OPC and TPC for evaluation.

III. TRANSITIONING PRODUCTS FROM RESEARCH TO OPERATIONS

The OSWT has developed an end-to-end NRT processing system to be implemented on all new and existing data. This system is unique in its design since it covers all phases of processing and distribution. Each phase has a feedback loop that allows for the immediate validation of a new product and the development and implementation of subsequent improvements as shown in Fig.1.

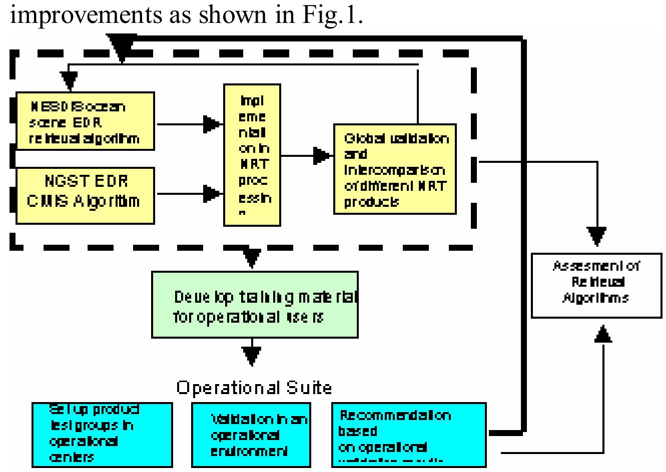

Figure 1 NOAA/NESDIS End-to-End development system.

. A very important characteristic of this system is that it engages the operational users, such as NWS, OPC and TPC, in the validation process. The critical point in achieving the proper feedback and maximizing the effective utilization of these data in the operational environment lies in the development and implementation of end user training tools. Through the experience gained with QuikSCAT (now routinely used operationally by OPC, TPC and many other international operational weather centers) it has been demonstrated that the education and training of the end user is of utmost importance. Direct interaction with the operational users has not only helped to improve their understanding of the products (thus allowing more effective use of the retrievals), but the resulting feedback has also helped the OWST to understand and focus resources on the issues that were most important to the operational community. This has allowed us to efficiently transfer products from the research and development phase into the operational environment.

IV. Evaluation of QuikSCAT in the Operational Environment

The QuikSCAT wind products from NOAA/NESDIS have been fully integrated into the operational environment at the OPC and the TPC. Both ocean and hurricane forecasters routinely use QuikSCAT winds in their analysis and forecast process.

The primary responsibility of the OPC is the issuance of marine warnings and forecasts for maritime users in order to foster the protection of life and property, safety at sea, and the enhancement of economic opportunity. The OPC also produces graphical and text forecasts of winds and seas for the extratropical high seas and offshore waters of the Atlantic and Pacific Oceans.

As part of the wind warning process, OPC produces a manual surface analysis) for the North Pacific and North. To produce the surface analysis, the OPC forecasters use the SLP guidance from the most recent GFS model run as a first guess. Based on the wind data from the GFS model, data buoys, ship observations and QuikSCAT the OPC forecasters locate areas of Gale, Storm and Hurricane Force winds and place the appropriate warning label on the surface analysis. In [1], Von Ahn et al. have demonstrated that the inclusion of QuikSCAT winds has made a significant positive impact on the warning process. In a recent impact study [1], it was revealed that when available, QuikSCAT winds were used to locate surface features and to identify the intensity and the extent of wind areas on OPC surface analyses 68% (Atlantic) and 50% (Pacific) of the time and the total number of wind warnings issued by the OPC increased by 10%in both the Atlantic and Pacific oceans. OPC forecasters have routinely observed QuikSCAT winds in excess of 63 kt (32.7 m s^{-1}) (Hurricane Force) in association with extratropical cyclones [4], giving them the ability to consistently detect and warn for these extreme events. QuikSCAT has also revealed wind speed gradients in the vicinity of SST gradients. Forecasters have been able to use this information as guidance to improve wind forecasts over the complex SST fields found in the Atlantic Offshore waters in the vicinity of the Gulf Stream [1].

Several concerns were uncovered during the course of the QuikSCAT evaluation. Precipitation is well known to be a source of errors in the wind field retrieved from QuikSCAT measurements [5]. Rain affected measurements influence both wind speed and direction retrievals:

1. At low wind speeds, under heavy rain conditions retrieved wind speeds are overestimated while at high wind speeds the opposite occurs. [6]
2. Wind direction retrievals affected by rain can be identified by direction that point in a cross track direction. However, this is not always the case. In many instances, although the wind direction is cross track the direction is actually in agreement with the synoptic situation (Fig.2.)

The QuikSCAT product contains a rain flag specifically designed to indicate wind vector retrievals that are possibly rain contaminated. However, this flag is overly conservative with too many false alarms especially at high wind speeds [7]. The rain contamination factor and the rain flag itself have been a source of confusion to the forecaster. [1]. Without a full understanding of the rain flagging process forecasters tended to discard all rain flagged data, often resulting in a loss of much useful data [7]. In Fig. 2 from [1], Von Ahn et al provide an excellent example of this. The QuikSCAT pass from 0800 UTC 04 November 2004 shows a large area of rain-flagged winds in the northeast quadrant of the low. Fig.2b shows the same QuikSCAT pass with the rain flag turned off. A large area of easterly winds can be found to the north of the low center. On the surface analysis from 0600 UTC 04 November 2004 (Fig.2c) it can be seen that the observed winds to the north of the low are in fact easterly. In this case, although the wind directions are cross track they are in agreement with the synoptic situation and are in fact not rain contaminated. This example further illustrates the fact that the need for forecaster training is imperative for full utilization of the QuikSCAT product.

The TPC/National Hurricane Center (NHC) has also shown significant impact in operations using QuikSCAT wind vectors. Impact studies have shown that QuikSCAT winds can be useful in determining the extent of 34-kt winds in tropical storms or hurricanes, as the outer extent of these wind areas can be located outside the area of heavy rainfall, particularly in major hurricanes. However, QuikSCAT estimates of tropical cyclone intensity are less reliable due to rain contamination and resolution issues. QuikSCAT can also be helpful in determining the intensity of some tropical storms and Category 1 or 2 hurricanes, although careful interpretation of the data by the forecaster is required. In the TPC/ Tropical Analysis and Forecast Branch (TAFB), QuikSCAT winds have improved surface analyses and forecasts issued by the by improving the placement of surface features (i.e., allowing the inclusion of the intertropical convergence zone on the surface map) and identifying high wind areas. In particular, QuikSCAT data

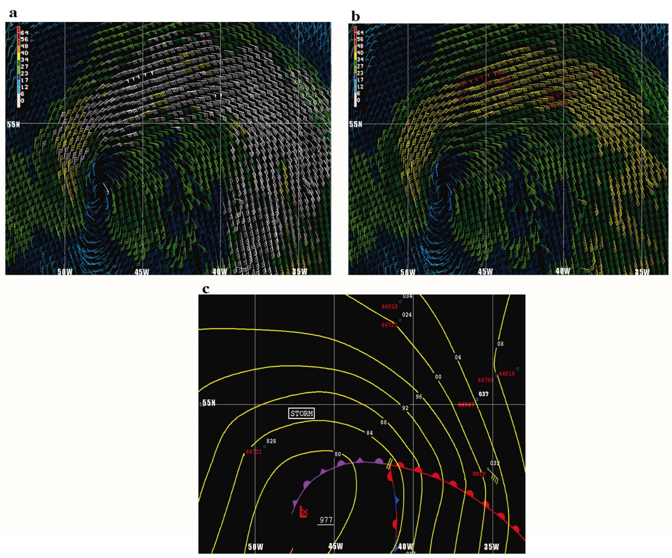

Figure 2 (a) QuikSCAT winds for 0800 UTC 04 November 2004 centered on54ºN, 43ºW with the rain flagged white wind barbs showing possible rain contamination. (b) Same as in (a) but with rain flag turned off. (c) OPC manual Surface analysis for 0600 UTC 04 November 2004

have been very useful in monitoring and forecasting high wind events in the Gulf of Tehuantepec. Prior to the advent of QuikSCAT, the extent and magnitude of many of these wind events was unknown due to a lack of observations.

The importance of user education was once again illustrated in the impact study within the TPC. The design of the QuikSCAT instrument results in up to four possible wind direction solutions, or "ambiguities" in each wind vector cell. Incorrect ambiguity selection can cause significant errors in the location of tropical cyclone (TC) centers in the QuikSCAT wind solution. Forecasters at the TPC have found that TC center locations from the automated QuikSCAT wind solutions are often biased to the southwest. As a result, some forecasters at TPC have begun to use a manual analysis of the ambiguities to locate the center of a tropical cyclone. In some cases this analysis can be also used to help determine if a closed surface circulation exists at all. However, without a thorough understanding of and adequate training in the utilization of the ambiguities their effective use as an analysis and forecast tool would be greatly limited.

V. Data Display Capabilities

The impact studies and surveys conducted by Von Ahn et al [1] have shown that the positive impact of QuikSCAT wind vectors in the operational environment is not only due to the quality of the data (the reliability and timeliness of delivery, the large swath width and the large retrievable wind speed range) but to the ability to view the data directly within the operational workstations. These studies have also identified that the need for appropriate training and documentation is absolutely necessary in order to utilize the data to the fullest extent.

A. National Centers- National Centers Advanced Weather Interactive Processing System (N-AWIPS)

A good understanding of the nature and proper use of QuikSCAT data has had a significant impact in the utilization of these data in operations. In [1], Von Ahn et al describe this impact nicely.

The operational forecast centers of the National Centers for Environmental Prediction (NCEP) use the N-AWIPS workstations are used to generate all graphical analyses and forecast products. The display capabilities of each center's N-AWIPS workstations have been specifically designed to accommodate the specific mission and product suite. When QuikSCAT winds first became available, to OPC forecasters were only able to access them via the Internet through the NESDIS Office of Research and Applications (ORA) webpage: http://manati.orbit.nesdis.noaa.gov/QuikSCAT. While the Internet provided the forecasters the capability to look at the QuikSCAT winds, the usefulness was limited. Because the QuikSCAT data could not be displayed on the N-AWIPS workstation forecasters were unable to overlay or underlay the other observational data sets with the QuikSCAT winds. In 2001, QuikSCAT winds were incorporated into the the N-AWIPS workstations, providing forecasters with the ability to display and overlay a variety of fields using the same map background while in operational product generation mode. Improvements to the display that were made using input from the forecasters greatly improved the utilization of the data. In [1], Von Ahn et al provide an excellent example. Initially the time label on the display indicated the processing time rather than the actual pass time. Since several swaths are processed and displayed at the same time, the forecasters were unable to determine the exact time of the wind data from an individual pass. As a result, forecasters often disregarded the data. To correct this problem, the exact time of each scan line was added to the QuikSCAT displays in intervals as small as one minute. Additional options for displaying wind speeds have increased the utilization of QuikSCAT wind data. Wind speed categories are color coded differently for rain-flagged data and non rain-flagged data The default colors for non-flagged winds are coded to preset wind speed categories. The default for rain-flagged winds is white to allow for easy identification of potential rain contamination. Forecasters have the option to change the colors and the wind speed intervals to suit their individual preferences including the ability to display the rain-flagged winds using the same color scheme as the non-flagged winds. The usefulness of an observational data set in the operational environment and thus the ultimate success is greatly dependant on the design and flexibility of the display capabilities.

B. Weather Forecast Offices (WFO)- Advanced Weather Interactive Processing System (AWIPS)

QuikSCAT winds were made available to NWS WFO's via AWIPS workstations in the spring of 2004. This enabled NWS WFO's with coastal responsibility to view QuikSCAT winds when preparing coastal forecasts. Unlike its counterpart (N-AWIPS) in the National Centers the display capabilities were not as flexible or user specific. In addition no documentation or training was provided. This was problematic as indicated by WFO forecasters: “As with many of these types of things, the training investment by NWS has been slim to none when the data are first made available. Initiatives/technologies like this always seem to be on the Internet first and then some day it shows up in AWIPS. Then when we get it, only some use it. We should actually make it part of our daily briefing procedure, but have not yet done so.”[8]

In [1] Von Ahn et al demonstrated the need for all observational datasets to be available within the operational workstation. In addition to AWIPS WFO’s utilize other tools in their daily operations. The data sets need to be incorporated into all operational tools to be completely utilized. This became evident in a recent survey conducted at various coastal WFO’s [9] ‘Offices across the country are equipped with surface analysis tools like Local Analysis and Prediction System (LAPS) and Mesoscale Analysis and Prediction System (MAPS), Advanced Regional Prediction Data Analysis System (ADAS), etc. It would be nice to add the capability to these tools to ingest these satellite-derived vectors. This would improve substantially the quality of the analysis over water and the usefulness of these tools when using them as part of the forecast and warning process and for populating grids”[9].

VI. Development of Training materials

A. *The need for training*

With the development of new advanced technologies for measuring ocean surface winds it is evident that modifications to existing educational material are needed. As the science of remote sensing is a relatively young and therefore rapidly changing discipline, the present formal education system cannot adequately keep up with these advances. The forecasting techniques that use these new technologies can be very different from those described within traditional textbooks. Operational users are often presented with these new techniques with insufficient education in their use.

Although some general educational material is available via the Internet, none of this material specifically addresses the operational utilization of actual NOAA ocean wind products. This deficiency has resulted in an inefficient use of new technologies as they are transitioned from research into operations. This was exhibited when QuikSCAT data was introduced to the forecasters in NRT. Although measurements of ocean surface winds measured by the SeaWinds scatterometer on board the QuikSCAT satellite were provided to the operational community almost immediately after the launch of the satellite in June 1999, it took several years for this product to become widely utilized within the operational community. The main reason for the delay in use of these valuable data was lack o understanding of the information provided. It was only after the OSVWT developed preliminary training material and started to educate the users that these data became utilized more extensively. This became evident when QuikSCAT usage increased after OPC forecasters were provided with a QuikSCAT Winds tutorial. This was first presented as a seminar and then made available via the Internet (http://www.opc.ncep.noaa.gov/QuikSCAT/QuikSCAT_Winds_Tutorial_files/frame.htm.) This tutorial not only educated the forecasters on the theory of scatterometry, the QuikSCAT measurement method including the measurement geometry, wind algorithm and ambiguity selection process) but on the available products and data concerns. Today, QuikSCAT represents the main global source of ocean wind information within the operational community.

B. *Proposed Training plan*

By direct interaction with the operational users, the OSVWT not only fostered a better understanding of and more effective use of the scatterometry ocean wind products, but also provided insight into the issues that are important to the operational community. Training material for all current and future ocean vector wind products developed and provided by NOAA/NESDIS will be designed with the goal of showing how to access data and import the data into the operational workstations, and then to properly interpret the data.

In cooperation with OPC and TPC the OSWVT will develop training material in the form of tutorials that will specifically explain the proper usage of all ocean vector wind products developed and provided by the OSWVT at NOAA/NESDIS from both passive and active microwave instruments. A test user group within the OPC will be developed for the initial validation and improvement of current and new training material in order to “understand, predict and explain fundamental processes and interactions of the atmosphere, climate, ocean and coastal ecosystems” as stated in NOAA’s education program. Once the material has proven useful in the operational environment, it will be made available to the entire user community via the Internet.

To build awareness and engaged young minds into the scientific environment the OSVWT plans to create a science tutorial specifically tailored to the K-12 audience. This module will contain basic information about the formation of tropical and extra tropical storms and will be supplemented with actual pictures and movies taken during experiments. Material will be made available via the Internet and will also be presented in local elementary, middle and high schools.

Once the initial material has been developed it will be presented to educators in order to “prepare teachers to understand and present NOAA science to “promote careers in environmental sciences to ensure a future workforce reflects into the nations diversity and trained disciplines critical to NOAA’s mission” as stated in NOAA’s education program. TO achieve this it is proposed to host an educator workshop at the OPC in order to bridge the gap that exists between the knowledge gained by operational forecasters through the daily use of remotely sensed ocean surface winds and education material used to train mariners on the topic of hurricane force extra tropical cyclones, cyclone structure and evolution, the impact of underlying ocean temperature on near surface atmospheric winds and forecasting techniques. Teachers from state maritime colleges, federal academies and professional training institutions would be among those invited to participate. This workshop would be hosted by members of both the research and forecast community and would be held within the operational forecast environ mint to promote hands on experience. The knowledge gained and the material provide will be made available to be incorporated into future lesson plans to train mariners and forecasters.

VII. SUMMARY

Since the launch of QuikSCAT satellite in June 1999, ocean winds measured by the on-board scatterometer have been provided in near real-time (NRT). Although these measurements were provided to the operational community almost immediately after the launch of the satellite, it took several years until this product started being used more widely in the operational community. The main reason for the delay in use of these valuable data was lack of understanding of the information provided. Only after development of some preliminary training material and personal interaction with users did these data became used more widely. Today QuikSCAT data represent the main global source of ocean wind information.

The QuikSCAT project over the past year has developed new wind vector retrieval algorithms and products that OSVWT will make available in near-real time to operational community this year. Since new wind vector data from QuikSCAT measurements will somewhat different from ones that are currently available the successful implementation of new products will depend on user's ability to understand and properly interpret these changes.

The NRT wind products produced and distributed by the NOAA/NESDIS Ocean Surface Vector Winds Team (OSVWT) are used by operational forecasters, scientific researchers and the marine community. The scientists from the OSVWT have also been instrumental in the development of new and more sophisticate wind retrieval techniques. With this development has come the realization that outreach to new existing and potential users is absolutely fundamental if these data are to be exploited in a manner that maintains scientific credibility and benefits society. A very important characteristic of ongoing product development is the engagement of the operation user, (such as the OPC and TPC) in the validation process. The critical point in the achievement of proper feedback and maximizing the effective utilization of these data lies in the development and implementation of end user training tools. Experience with QuikSCAT wind products, which are now routinely used by OPC TPC and many other international weather centers has shown us that user education and training is of the utmost importance. In cooperation with OPC and TPC the OSVWT will develop training material that will specifically explain the proper usage of the ocean vector wind products they develop and provide at NOAA/NESDIS from both passive and active microwave instruments. A test user group has been formed within the OPC for initial validation and improvement of the training material. Once the initial material has proven useful in the operational community it will be made available to the entire user community.

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